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T. A. Nieminen

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# Project-based assessment for graduate coursework in physics

*T. A. Nieminen*

School of Physical Sciences, The University of Queensland, Australia

**Abstract**

Project-based assessment, in the form of take-home exams, was trialed in an honours/masters level electromagnetic theory course. This assessment formed an integral part of the learning experience of the students, and students felt that this was effective method of learning.

**Introduction**

Graduate coursework in physics—the coursework component in honours and masters courses—is intended in large part to prepare students for postgraduate research and the professional practice of physics. Assessment often depends largely, or even entirely, on examinations of the traditional variety—proofs and problems, to be completed in perhaps two or three hours. A necessary result of this format is that the problems must be simple enough for able students to complete satisfactorily in the time available. As I have rarely encountered the need for such proofs or solutions to such simple problems in the professional practice of physics, and in any case, these are the type of things which can be easily looked up textbooks, I wondered as to how well such assessment methods meet the intended requirements of the courses.

Furthermore, the capability of students to memorise required proofs and solutions until the end of the examination, and then to promptly forget a large portion of this, suggests that long-term learning is not enhanced by traditional examinations.

Considering the above points, I entertained the possibility of alternative forms of assessment. Observations on the lack of correlation between examination results and my perceptions of student understanding provided further incentive.

Accordingly, I replaced traditional examinations in an honours/masters-level course in electromagnetic theory with project-based take-home exams. Students would complete one question in approximately one week, and could make use of the tools available to professional physicists: the research literature, libraries, and colleagues. Questions were chosen to require an estimated two days of work.

I discuss the implementation of project-based assessment, and the results of two years of testing. Finally, I consider some future possibilities.

# Implementation

Two project-based take-home exams were conducted in the discussed course in each of 2005 and 2006. In both cases, in the first instance, the topic was electrostatics, and all students attempted the same question. In the second instance, the topic was electromagnetic waves, and students could choose one question from a total of five. Students were usually given five or six days in which to attempt the question; this time included one weekend. Questions were designed with the intent that two student-days would be required to complete the tasks. The topics had been covered beforehand in lectures.

For example, the first project-based exam in 2005 was:

A colleague approaches you for advice. She is planning an experiment in which a cubic conductor will be charged to a potential. To simplify the analysis, she hopes that it will be possible to assume that the field is a Coulomb field (ie like the field due to a point charge). How closely does the field of a conducting cube resemble that of a conducting sphere?

You might wish to consider some of the following questions:

1. How far away from the cube do you need to be before the field closely resembles the field due to a sphere?
2. Is the “equivalent sphere” at the same potential as the cube?
3. What is the field due to a conducting cube?
4. What about the effect of the ground? Assume that the ground can be treated as a perfectly conducting infinite plane.

The range of questions for the second exam is illustrated by the 2006 selection:

1. Investigate the transmission and reflection of long pulses by an anti-reflection dielectric layer (or some other interesting type of layer(s)).  
You may wish to perform the calculation for a periodic sequence of pulses.
2. What is the extinction cross-section of a sphere? Calculate the cross-section as a function of radius for a variety of types of sphere.  
Under what conditions might experimental measurements reproduce such curves?
3. What is the smallest resonator that can be made from a circular loop of optical fibre that has a  $Q$  close to that of a large circular loop of optical fibre?
4. Design a passive antenna array, with one driven element, or an active array, with all elements driven, for broad-band directivity. Calculate how the radiation pattern changes as a function of frequency.
5. Is it possible to build a Bragg mirror that is large enough so that its structure can be clearly seen and can be used with a laser pointer for demonstration purposes?  
Calculate or estimate the maximum thickness of each layer.

It was intended that the question in the first exam could be approached either theoretically or computationally, while the second exam included both questions suited to a theoretical approach (eg Q3 above), questions suited to a computational approach (eg Q2), and those amenable to either.

Students were required to hand in a written report, and to make an oral presentation in class. There were no specific requirements for either the written report or oral presentation, other than clear communication of methods and results.

The two project-based exams together constituted approximately 40% of the total assessment for the course, with the remaining assessment consisting of assignments and minor oral or written in-class exams.

## Results

Students were, in almost all cases, able to complete the exams in the time allowed. The time spent by the students on the questions was greater than expected, with three days being typical.

The variety of methods employed by the students was surprising; for the first exam in 2005, where all students attempted the same question, there were five completely distinct strategies used by the 13 students. Similarly, for the second exam in each year, each of which had five questions to choose from, every question was attempted by at least one student. Students frequently chose computational methods of solution. While students did make use of the research literature, this was to a lesser extent than expected. This is likely to be a result of many of the computational methods being relatively straightforward.

Student performance varied from good through to superb. The quality of presentations noticeably improved (students also gave oral presentations for a minor assignment and for the major assignment). Students were able to demonstrate an understanding of the problem and the related physics and mathematical or computational methods beyond merely demonstrating the ability to provide a numerical answer or proof.

Written reports varied from seven pages through to over 30, with 15 pages being typical, not including attached listings of computer code. Thus, these assessment tasks also provide a significant degree of practice in written scientific communication.

Some students made extensive use of the research literature, while others made little or no use of literature other than textbooks. In part, this depended on the nature of the question chosen, but also reflected individual approaches to the problems.

### Student feedback

Students generally found that the problems were difficult and required a significant amount of work. Despite this, they also found the experience enjoyable. Students reported that they learned more from the project-based assessment than any other assessment. Several students recommended that the number of project-based take-home exams be increased, so as to cover a larger amount of the course content. Student feedback included both unsolicited and solicited feedback, primarily verbal.

## Discussion

Overall, I believe that the project-based assessment described above was successful. Rather than simply testing knowledge of and ability to apply the course material, the take-home exams provided an intensive learning experience for the students. This learning included not only the relevant portions of the core course content, but also useful skills such as how to make use of the research literature and oral and written scientific communication.

Based on the results of this trial, the number of such project-based take-home exams will be increased, possibly to five, and the entire course content will be covered. Prior to the first assessment task for a semester, the assessment method will be discussed with the class, and guidelines for the written report and oral exam will be given. The discussion will include ethical standards and how to make use of the research literature. While a formal discussion of these issues may not be necessary for honours or masters level students, I believe that it could still benefit them. Such a discussion would be essential if the course were an undergraduate course.

In 2005 and 2006, the other major component of the assessment was an assignment on a relevant topic of the student's choice. The above plan to increase the number of project-based take-home exams will essentially result in the elimination of the assignment. This will have the advantages of spreading the work more evenly over the entire semester—most students leave the bulk of the work on the assignment until shortly before the due date—and assessing a larger part of the course material. Although the assignment allowed students to investigate one aspect of the course in depth, this was at the cost of breadth. It may be of value to retain an assignment as an optional piece of assessment, perhaps to replace one or two take-home exams that cover similar material, for students who wish to attempt publication-quality work—approximately 20% of the students have produced work of this standard in 2005 and 2006 (for example, Pfeifer and Nieminen 2006), and it would be a pity to deny students this opportunity.

The time required for the oral presentations is significant, and when the number of such exams is increased, a significant portion of the total class time during the semester will be occupied by such presentations. However, I feel it is important to retain the oral presentations, since scientific communication is an important learning objective for courses intended for the training of professional physicists. The imposition of strict time limits for presentations is necessary—when students were given a recommended time of 15 minutes for presentations, while some students kept their presentations within this time frame, others gave 40 minute presentations. With 12 students giving presentations of 15 minutes each for four take-home exams, approximately  $1/4$  of a 4 contact hour per week course will consist of presentations. If such take-home exams replace a traditional final exam, there is no need for drill problems to prepare students for the final exam, which often occupies a large part of tutorial time, this time should be available.

A number of issues, which include potential problems, deserve further consideration.

## **Large classes**

Large classes may not allow enough time for students to give oral presentations for every exam. Some possible solutions include students giving only one or two oral presentations over the semester, eliminating oral presentations entirely (but see the next item below), or group-work. If students were to work in groups, then one student from each group could give the presentation on behalf of the group, with a different student presenting for each exam. Group-work would also reduce the time required to read the written reports if the group submits a single report. This, of course, would leave one with the problem of fairly determining grades for individual students.

## **Plagiarism**

The oral presentation, with the opportunity to question the student, is an important part of determining the level of understanding that the student has. As a result, it is useful for the detection of plagiarism—if the student has not done the work, they are less likely to understand it. It is important to clearly communicate the ethical standards expected of the students, the extent to which they can make use of the work of others, and how to properly acknowledge such use of other's work.

## **Workload**

The effort demanded of students for a take-home exam is significant, and potential clashes with other major demands on student time should be watched for.

## Instant answers

For the first exam each year, where all students attempted the same question, at about the time when students were completing the exam after almost a week of effort, it became apparent that it was possible to cover most elements of the problem in under five minutes. For example, with the cube problem given above, the symmetry required of the potential means that the first non-zero multipole moments beyond the monopole moment are the  $2^5$  terms (only the odd- $n$   $2^n$  terms can be non-zero, and the  $2^3$  terms must be zero because they cannot give cubic symmetry), and hence all non-monopole contributions to the potential drop off at least as fast as  $r^5$ . With this, one can very quickly provide a reasonable answer to the question as posed.

## Impossible questions

One interesting possibility is to set questions that are difficult to the point of impossibility. The paths by which the student attempts to approach the answer, and the points at which these are abandoned may well demonstrate the student's understanding better than a straightforward successful solution. It may well be wise to warn students beforehand of the possibility of impossibility to avoid excess student anguish and stress.

## Experimental answers

The inclusion of problems that can include or require experimental measurements can allow a close integration of theory and experiment. This could be a useful strategy for adding a small experimental component to a theoretical course.

## Summary

Project-based take-home exams were a successful learning and assessment method, and were popular with the students. Students reported that they learned more from them than from other types of assessment, and recommended that the number of such take-home exams be increased. This recommendation will be adopted.

## Reference

Pfeifer, R.N.C and Nieminen, T.A. (2006). Visualization of Čerenkov radiation and the fields of a moving charge. *European Journal of Physics* **27**, 521-29.